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ORIGINAL PAPER

Carbon stock estimation for tree species of Sem Mukhem sacred forest in Garhwal Himalaya, India

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Abstract: Carbon stock estimation was conducted in tree species of Sem Mukhem sacred forest in district Tehri of Garhwal Himalaya, Uttarakhand, India. This forest is dedicated to Nagraj Devta and is dominated by tree species, including *Quercus floribunda*, *Quercus semecarpifolia* and *Rhododendron arboreum*. The highest values of below ground biomass density, total biomass density and total carbon density were (34.81±1.68) Mg·ha^{-1}, (168.26±9.04) Mg·ha^{-1} and (84.13±4.18) Mg·ha^{-1} for *Pinus wallichiana*. Overall values of total biomass density and total carbon density calculated were 1549.704 Mg·ha^{-1} and 774.77 Mg·ha^{-1} respectively. Total value of growing stock volume density for all species was 732.56 m^3·ha^{-1} and ranged from (144.97±11.98) m^3·ha^{-1} for *Pinus wallichiana* to (7.78±1.78) m^3·ha^{-1} for *Benthamidia capitata*.

Keywords: carbon; management; sacred forest; biomass; density

Introduction

The Intergovernmental Panel on Climate Change (IPCC) states in its Third Assessment Report (IPCC, 2001) that most of the global warming observed over the last half century is attributed to human activities. IPCC predicts that anthropogenic emission of greenhouse gases (GHGs) will raise the global mean surface temperature from 1.4 to 5.8°C over the next century. Depending upon the succession stage, specific disturbance, or management intervention, the forest can act as a source and as a sink (Masera et al. 2003). Forests act as sinks by increasing aboveground biomass through increased forest cover and by increased levels of soil organic carbon (SOC) content. By converting shrub/pasture lands and agricultural fields, or degraded forests into forests, the rate of respiration from plants, soil, and dead organic matter is exceeded by Net Primary Production (NPP). This leads to sequestration of CO_2 from the atmosphere to the terrestrial ecosystem. On average, 50% of the biomass is estimated as the carbon content for all species of trees. Forests play a profound role in reducing ambient CO_2 levels as they sequester from 20 to 100 times more carbon per unit area than croplands (Brown et al. 1999). Bass et al. (2000) identified three carbon management strategies in forests, which are also compatible with community-managed forests. These are carbon sequestration, carbon conservation, and carbon substitution. Community-based forest management as a mainstream forestry strategy formulated around the late 1970s as an approach to mitigate increasing deforestation and forest degradation and address the negative impacts on rural livelihoods. In Asia, this management approach quickly became widespread, and, different forms of community involvement in forest management and protection have evolved. Another kind of community conservation effort involves dedicating a particular forest or a patch of forest to a deity for conservation purpose and holding it sacred. Sacred groves or temple forests are one of the oldest forms of conserved natural forests. Sacred forests are often fragments of the originally extensive forest ecosystem that are particularly diverse in trees and associated species. These are ecologically important because they provide habitats for rare, endemic and endangered species of flora and fauna (Nair et al. 1997) and have a high conservation value in spite of their typically small areas (Boraiah et al. 2001).

Garhwal Himalaya is one of the locations in India known as

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land of gods where forests are associated with deities and have centrally located temples. Our study was carried out in Sem Mukhen sacred forest to estimate the carbon stock storage in trees.

Materials and methods

Sem Mukhem sacred forest is situated near the village Mukhem in the Pratap Nagar block of Tehri district, of Garhwal Himalaya (N 30°34′40.5″–30°34′28.7″ to E 78°26′59.1″–78°26′11.7″) at elevations of 2,200 to 2,750 m above m.s.l. The study area is a combination of reserve forest and Van Panchyat (community forest) forest area. The Sem temple is situated at the top of a hill about 3–4 km from the village Muhkem, which is 2 km from the motor head of Khamba Khal. Geographically the district can be divided into hill and valley areas. Hot climate is the characteristic of valleys in summer and extreme colds in winter. Higher peaks are snow clad throughout the year. The mean minimum and maximum temperatures are 0.20°C and 32°C, respectively, with average rainfall of 1,706 mm. The inclusiveness of the Local fairs include worship of sacred geography and sightseeing (Kauthik), logging for togetherness (Mela), religious communion with the divine, and respect for the changing rhythms of nature (Ausar), (Purohit 2001).

Tree sampling quadrats of 10 m×10 m were set out over the entire study area. Quadrat locations were selected randomly to represent the entire forest area considered sacred. We measured height and cbh (circumference at breast height) of all trees within sampling quadrats. After laying quadrats, we measured individual trees. Tree height was measured using a Ravi multimeter. Plants with cbh ≥30 cm were considered trees Knight (1963). Density was calculated using the formula given by (Mishra 1968). The growing stock density (GSVD) was estimated using volume tables or volume equations based on the Forest Research Institute (FRI) and Forest Survey of India (FSI) publications for the respective species (Chaturvedi 1973; Sharma and Jain 1977). The estimated GSVD ($m^3 \cdot ha^{-1}$) was then converted into above ground biomass density (AGBD) of tree components, which was calculated by multiplying GSVD of the tree species by appropriate biomass expansion factors (B_{EF}) (Brown et al. 1999). The B_{EF} for hardwood and pine was calculated using the following equations:

$$B_{EF} = \exp\{1.9 - 0.34 \times \ln G\} \tag{1}$$

where, G is the growing stock density ($G \geq 200$ $m^3 \cdot ha^{-1}$). B_{EF} = 1.0 (G>200 $m^3 \cdot ha^{-1}$).

The B_{EF} for pine was calculated as follows:

B_{EF} = 1.68 $Mg \cdot m^{-3}$ (G < 10 $m^3 \cdot ha^{-1}$), B_{EF} = 0.95 (G = (10−100) $m^3 \cdot ha^{-1}$); B_{EF} = 0.81 (G > 100 $m^3 \cdot ha^{-1}$).

Using the regression equation of Cairns et al. (1997) the below ground biomass density, B_{GBD} (below ground biomass density) was estimated for different tree species as follows:

$$B_{GBD} = \exp\{-1.059 + 0.884 \times \ln A + 0.284\} \tag{2}$$

A_{GBD} (above ground biomass density) and B_{GBD} were added to get the total biomass density (T_{BD}). The total C density (T_{CD}) was computed using the following formula:

$$C = B_o \times (0.5) \tag{3}$$

where, C is Carbon ($Mg \cdot ha^{-1}$); B_o is Biomass ($Mg \cdot ha^{-1}$), (IPCC 2000).

Results and discussion

Sem Mukhem sacred forest was dominated by tree species, including *Quercus floribunda*, *Rhododendron arboreum*, *Quercus leucotrichophora*, *Quercus semecarpifolia* and associated species. Values for density, biomass and C stocks varied by tree species across the study area (Table 1) Total value of growing stock volume density for all species was 732.56 $m^3 \cdot ha^{-1}$ and ranged from (144.97±11.98) $m^3 \cdot ha^{-1}$ for *Pinus wallichiana* to (7.78±1.78) $m^3 \cdot ha^{-1}$ for *Benthamidia capitata*. The overall value of above ground biomass density is 1224.91. This value lies on the higher end of the range of reported values from India and other parts of Asia (Tiwari and Singh 1987; Hall and Uhlig 1991). These values are also much higher than the reported values of Singh et al. (1994) for mixed deciduous forests in the central Himalaya.

The higher values calculated in the present study might reflect the relative lack of disturbance in the Sem Mukhem forest, which is part of a reserve forest and is protected due to the respect for deities among local villagers. This forest is dedicated to Nagraj Devta and use of tools for green felling is banned. However collection of fallen biomass and grasses is allowed. This climax forest is stable and fully mature with large basal area of tree species. Tree growth is vigorous, thus accumulation of carbon stock is rapid. Depending upon the successional stage, specific disturbance, or management intervention, the forest can act as a source and a sink (Masera et al. 2003). Highest value of above ground biomass density was (133.44±7.36) $Mg \cdot ha^{-1}$ for *Pinus wallichiana*, followed by *Rhododendron arboreum* ((100.43±2.83) $Mg \cdot ha^{-1}$), whereas lowest values were (8.34±1.52) $Mg \cdot ha^{-1}$ for *Cotoneaster confuses* and (8.56±1.19) $Mg \cdot ha^{-1}$ for *Benthamidia capitata*. Total above ground biomass for all species was 1224.91 $Mg \cdot ha^{-1}$. The highest values of below ground biomass density, total biomass density and total carbon density were (34.81±1.68) $Mg \cdot ha^{-1}$, (168.26±9.04) $Mg \cdot ha^{-1}$ and (84.13±4.18) $Mg \cdot ha^{-1}$ for *Pinus wallichiana*[1] for *Pinus wallichiana* respectively for *Pinus wallichiana*, followed by *Quercus floribunda* with below ground biomass density of (27.45±2.08) $Mg \cdot ha^{-1}$, total biomass density of (134.07±12.24) $Mg \cdot ha^{-1}$ and total carbon density of (67.03±6.12) $Mg \cdot ha^{-1}$. Minimum below ground biomass density was (1.95±0.10) $Mg \cdot ha^{-1}$ for *Prunus cerosoides* (Table 1).

Table 1. Biomass and carbon stocks by tree species

Name of the species	Density (individual·ha^{-1})	G_{SVD} (m³·ha^{-1})	A_{GBD} (Mg·ha^{-1})	B_{GBD} (Mg·ha^{-1})	T_{BD} Mg·ha^{-1}	T_{CD} (Mg·ha^{-1})
Abies spectibilis (D.Don) Spach.	50.00	62.84±15.78	82.67±72.90	22.95±3.45	109.25±18.03	54.62±9.01
Acer caesium Wallich ex Brandis	14.00	11.74±3.64	31.34±7.18	9.47±2.14	40.81±9.90	20.40±4.95
Banthmidia capitata (Wallich ex Roxb.) Hara	38.00	7.78±1.78	8.56±1.19	3.03±0.36	11.604±1.55	5.80±0.77
Cotoneaster confuses wallich	28.00	7.02±1.65	8.34±1.52	2.96±0.45	11.3±1.43	5.65±0.67
Eurya acuminata DC	10.00	10.61±2.89	31.23±5.31	9.60±1.42	40.83±6.74	20.41±3.37
Ficus neriifolia Smith	4.00	21.09±8.91	49.44±10.10	14.42±3.70	63.87±18.03	31.93±9.00
Ilex dipyrena Wallich	30.00	9.28±1.92	27.88±3.49	8.64±0.94	36.53±4.43	18.26±2.21
Juglans regia L.	6.00	19.51±4.89	47.27±8.11	13.88±2.12	61.15±10.23	30.57±5.11
Lyonia ovalifolia (Wallich) Drude,	110.00	26.86±3.82	70.18±6.84	19.26±1.67	89.44±8.51	44.72±4.25
Myrica esculanta Buch-Ham. Ex D.Don.	8.00	31.46±5.47	64.96±7.0	18.39±2.06	83.35±10.14	41.67±1.75
Persea duthiei (King ex Kook.f.)	4.00	17.79±4.93	44.34±11.83	13.11±3.11	57.45±14.94	28.72±7.47
Pinus roxburghii Sargent	56.00	26.82±0.18	53.79±6.83	2.59±0.96	56.38±6.92	28.19±3.46
Pinus wallichiana A.B. Jackson	14.00	144.97±11.98	133.44±7.36	34.81±1.68	168.26±9.04	84.13±4.18
Populus ciliata Wallich ex Royle	6.00	16.01±7.23	40.19±12.40	11.94±3.27	52.13±15.67	26.06±7.83
Prunus cerasodis D.Don	18.00	6.90±1.35	23.41±2.81	1.95±0.10	25.37±3.08	12.68±1.54
Pyrus pashia Buch-Ham, ex. D. Don	60.00	10.5±1.51	30.19±2.73	4.27±0.37	34.46±2.79	17.23±1.40
Quercus floribunda Lindley ex Rehder	378.00	76.95±10.44	106.62±10.17	27.45±2.08	134.07±12.24	67.03±6.12
Quercus leucotrichophora A. Camus	130.00	30.61±2.78	57.66±5.13	16.20±1.28	73.86±6.41	36.93±3.21
Quercus semecarpifolia J.E Smith	94.00	65.15±34.62	81.95±15.65	21.54±1.67	103.49±19.10	51.74±9.55
Rhamnus viratus Roxb.	8.00	40.91±34.10	60.32±36.40	16.32±7.78	76.65±45.11	38.32±22.55
Rhododendron arboreum Smith, Exot.Bot.	154.00	60.75±2.52	100.43±2.83	27.04±0.69	127.47±3.57	63.73±1.78
Swida macrophylla (Wallich) Sojak	14.00	14.04±2.69	37.72±4.74	11.35±1.25	49.08±6.0	24.54±3.00
Symplocos ramosissima Wallich ex G.Don	24.00	12.97±3.31	32.98±5.51	9.91±1.45	42.90±6.96	21.45±3.48

Notes: G_{SVD} is Growing stock volume density; A_{GBD} is above ground biomass density; B_{GBD} is below ground biomass density; T_{CD} is total carbon density; Values are (Mean± SD).

Pinus wallichiana (a conifer) had greater total biomass density and total carbon density than other species. Few *Pinus wallichiana* trees were recorded in the forest, but all had large girth. Negi et al. (2003) observed that tree types generally store C in the order of conifer>deciduous>evergreen>bamboo. Sharma et al. (1977) showed that conifer-dominant upper west Himalayan *Abies pindrow* and moist *Cedrus deodara* forest had statistically higher C density than all other forest types. Lowest total biomass densities of (11.604±1.55) Mg·ha^{-1} and (11.3±1.43) Mg·ha^{-1} and total carbon densities of (5.80±0.77) Mg·ha^{-1} and (5.65±0.67) Mg·ha^{-1} were calculated for *Banthimidia capitata* and *Cotoneaster confuses*, respectively (Table 1). Lumber from both of these tree species is considered of secondary commercial importance and is used for making agricultural implements, fuelwood and for small construction timbers by local communities. Avoiding deforestation is a prominent carbon mitigation opportunity in land-use sectors (IPCC 2007). Net cumulative global CO_2 emissions from land-use change during 1850−1998 are estimated at (136±55) GtC (Giga ton carbon); of which 87% of emissions arise from forest areas (Bolin and Sukumar 2000) and are attributed largely to tropical deforestation. Overall total biomass density and total carbon density were 1549.704 and 774.77 Mg·ha^{-1}, respectively. Overall tree density for the forest was 1,258 trees·ha^{-1}, varying from 378 trees·ha^{-1} of *Quercus floribunda*, to 4 trees·ha^{-1} for *Persea duthiei* and *Ficus neriifolia*.

The Sem Mukhem forest is conserved by local communities for religious reasons and by government as a reserve forest. This study estimated the standing C stock in Sem Mukhem sacred forest and the results can serve as a baseline for the implementation of project activities. Community-based sacred conservation management of this forest strives to avoid deforestation and encroachment by combining local initiatives with programs of the Forestry Department. Tehri district of Garhwal Himalaya is under severe threat from construction of various hydropower projects that have already submerged large tracts of vegetation. The people of the area depend on forests to large extent to fulfill their needs for timber and non-timber forest products. Conservation of Sem Mukhem forest will lead to increased exploitation of surrounding unprotected forests if conservation management strategies are not developed and implemented in those areas. Sacred forests such as Sem Mukhem forest can provide models for sustainable utilization of forest resources in the region.

Conclusion

Our study documented the presence of many important species in Sem Mukhem forest and quantified the variation in carbon stock storage by species. Tree species growing at low densities will face the threat of extinction in future if protection strategies are

not tightened. From a carbon storage point of view, pine species should be planted. But to fulfil other villager needs such as supply of fuelwood, fodder and grasses, mixed forest is important. If new plantations are needed, local management authorities should be involved in plantation design. These types of community conserved forests will play a major role in long-term mitigation of GHG emissions because conversion of natural forests to farmlands and reservoirs is at peak in the area.

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